

Performance Evaluation of a Small-Scale Sugarcane Juice Extracting Machine

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SAO and NO designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Authors JBJ and SIO managed the analyses of the study. Authors YAU and AMS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The study was aimed at evaluating the machine performance of a fabricated prototype of a sugarcane juice extractor. The study was conducted in the Department of Agricultural and Bio-resources engineering, Ahmadu Bello University, Zaria in May 2018. The machine was evaluated using two varieties of cane; *Koma (saccharumbarberi)* and *Kantoma (saccharumofficinarum)* in a factorial experiment with five (5) levels of crushing roller speeds (20, 30, 40, 50 and 60 rpm) and three levels of feed rates: one (1) cane stalk, two (2) cane stalks and three (3) cane stalks arranged in 2x5x3 in completely randomized design. Average values of measured parameters obtained from the five crushing speeds were used in plotting graphs in order to establish the relationships that exist between the measured parameters and speed of operation. Data collected for output capacity and extraction efficiency were analyzed using a statistical analysis software (SAS version 9.0).

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Analysis of Variance (ANOVA) and the Duncan Multiple Range Test (DMRT) were computed at 1 and 5 % levels of significance. The results of performance evaluation showed that the best output capacities of 152.4 and 154.2 kg/hr and the best efficiencies of 72.1 and 63.4% were obtained at the speed of 30 rpm and feed rate of one (1) cane stalk for *koma* and *kantoma* varieties respectively. The extraction losses of 17.8 and 21.5% were also recorded at the speed of 60 rpm for the two varieties respectively.

Keywords: *Koma; kantoma; speed; output capacity; efficiency; extraction losses; sugarcane.*

1. INTRODUCTION

Sugarcane belongs to a large family of grasses, which contains more than 5,000 species. Included in this family are other economic crops such as barley, rice, and wheat. Sugarcane has the ability to trap the sun's energy and convert that energy into sucrose, which is stored as a sweet juice in the stalk of the plant [1]. Sugarcane (*Saccharum sp.*) is a tropical crop that usually takes between 8 – 12 months to reach its maturity. The height and diameter ranges from 2 to 7 m and 1.25 to 7.25 cm respectively [2].

Matured cane may be green, yellow, purplish or reddish considered ripe when sugar content is at its maximum, the hard perimeter of the stalk is known as rind and provides structural strength for the plant and protection of the inner material. The transport function is provided by vascular bundles, which run throughout the cane stalk. A cluster of fibrous sclerenchyma cells surrounds each vascular bundle. The majority of dissolved sugars in the stalk are stored in soft, thin-walled tissue cells called parenchyma [3].

Sugarcane provides high amount of energy for the nutritional requirement of both livestock's and humans. Based on its land use factor, its value of calories per unit area is highest for any plant [4]. Furthermore, due to the content of sugarcane-70% water, 14% fiber, 13.3% *saccharose* (about 10 – 15% sucrose), and 2.7% soluble impurities – it provides 60% of the world's sugar production while the rest is provided by sugar beet [5].

According to FAOSTAT [5], it was estimated that sugarcane was cultivated on about 26.0 million hectares, in over 90 countries, with a worldwide harvest of 1.83 billion tons. Brazil is the largest producer of sugarcane in the world. The next five major producers, in increasing order of amount of production were Mexico, Pakistan, Thailand, China and India. The cane producing countries in the tropical Africa includes: Mauritius, Kenya, Sudan, Zimbabwe, Madagascar, Cote Divoire,

Ethiopia, Malawi, Zambia, Tanzania, Nigeria, Cameroon and Zaire. Nigeria, being one of the most important producers of sugarcane has a land potential of more than 500,000 hectares of suitable cane field. Nigeria has vast human and natural resources (land and water), to produce enough sugarcane, not only to satisfy the country's requirement for sugar and bio-fuels, but also for export. The crop is mostly cultivated in the Northern states of Nigeria, where irrigation water is readily available.

Sugarcane is produced and sold in many local government areas of Kaduna state, including Makarfi, Giwa and Kudan. In the year 2013, about 20,000 households grew sugarcane in the state [6].

The world increasing demand for sugar is the major driver of sugarcane agriculture. Apart from cane sugar (sucrose), other products gotten from sugarcane include: bagasse, molasses, filter cake, falernum, rum, cachaça (a traditional spirit from Brazil) and ethanol. Bagasse, the residual woody fiber of the cane, is used for several purposes: fuel for the boilers and lime kilns, production of numerous paper and paperboard products and reconstituted panelboard, agricultural mulch, and a raw material for production of chemicals [7].

2. MATERIALS AND METHODS

The instruments that were employed in the machine testing are listed below:

- i. Photo Tachometer (digital): This was used in determining the various crushing speed on the machine in revolution per minute. It has a liquid crystal display with function annunciation and test range of 2.5 to 99,999 rpm.
- ii. Weighing balance: This was used to measure the various masses of the cane in kilogramme. BAYKON BX21 was used with maximum of 150 kg and minimum of 0.4 kg and error of 0.02 kg.

- iii. Stop Watch: This was used to measure the time of juicing in seconds.
- iv. Vernier calliper: This was used to measure the sizes of cane in millimetres.
- v. Measuring tape: This was used to measure the length of cane in centimetres.

ensure that slip that would occur with sugarcane during feeding in the case of plain crushing rollers is reduced to minimum if not eliminated [8]. The three (3) rollers arranged in triangular form crushes, presses and squeezes the stem at two different points during the crushing process.

2.1 Description of the Machine

The machine consists of the cane guide, the crushing unit, the juice collector, the power unit and the frame as shown in Fig. 1 while Table 1 shows the detail specifications of the machine.

2.1.3 The juice collector

The juice collector is made up of galvanize sheet metal. It is constructed in form of tray which is slanted so that the juice can flow into a container by gravity.

2.1.1 The cane guide

The cane guide is rectangular in shape with dimension of 225 mm by 100 mm metal sheet. It acts as support and also direct the sugarcane stem to the crushing unit. It also prevents the sugarcane stem from wobbling during the crushing process.

2.1.4 The power unit

The power unit consists of a 4.85 kW prime mover with belt and pulleys. The belt transmits power to the rollers via network of gear connections while the three rollers are connected via gear train. The prime mover was located at the base of the frame.

2.1.2 The crushing unit/Rollers (crushing chamber)

The crushing unit was made up of three (3) rollers, each 175 mm long and 70 mm in diameter. The clearance between the top and feed roller is 7.5 mm while the clearance between top and discharge roller is 4.5 mm. The three rollers were nulled and then grooved horizontally to increase the surface roughness for easy gripping of sugarcane. These arrangements

2.1.5 The frame and stand

The frame and the stand were fabricated using angle iron bars. The frame and stand provide supports for the juice extractors and the prime mover. The frame also provides rigidity when the machine is in operation.

Figs. 2a, 2b and 2c shows the pictorial view of the sugarcane juice extracting machine.

Table 1. Machine specifications

Components	Dimension	Value
Frame	Length	948 mm
	Width	480 mm
	Height	914 mm
Roller	Length	315 mm
	Diameter	90 mm
Pulley	Driving	100 mm
	Driven	400 mm
	Diameter	25 mm
Gear	Driving	64 mm
	Driven	418 mm
	Diameter	25 mm
Shaft	Length	400 mm
	Diameter	25 mm
	Diameter	25.5 mm
Operating Speed		72 rpm
Maximum cane diameter		32 mm
Power (Watt)	Diesel Engine	5hp

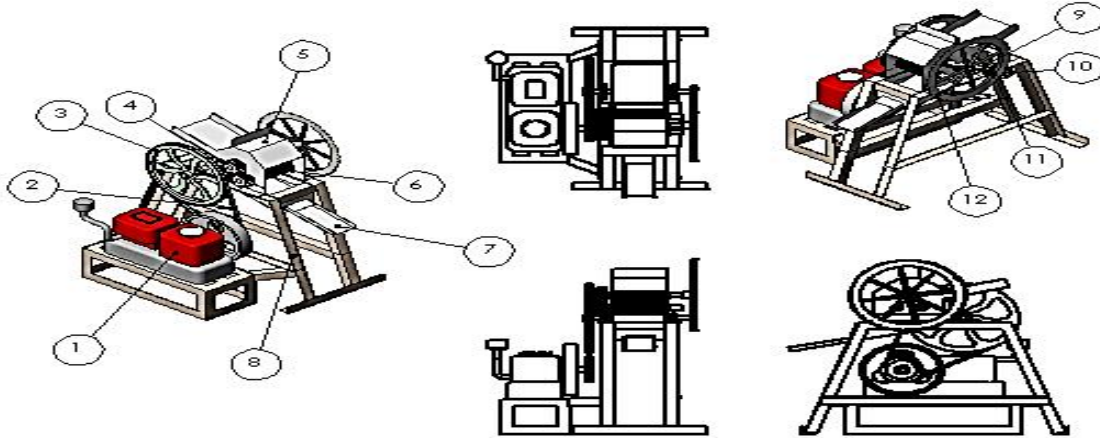


Fig. 1. Isometric view of the sugarcane juice extracting machine



Fig. 2a. Assembled sugarcane juice extractor



Fig. 2b. Collecting tray in container



Fig. 2c. Bagasse outlet

2.2 Experimental Procedure

The machine testing was undertaken to assess the effective performance of the machine components and to investigate the machine efficiency. Two varieties of sugarcane were used for the evaluation; variety one (v_1) is called “koma” (*saccharum barberi*). It is an industrial

sugarcane. This is one of the varieties used in making sugar in sugar refineries, it is also used in making brown sugar. This variety was obtained from Makarfi local government area of kaduna state, Nigeria. Variety two (v_2) is called “kantoma” (*saccharum officinarum*). This is a common and dominant variety in Zaria metropolis. Sorting was carried out to obtain

sugarcane of equal sizes of 3 cm (30 mm) and it was then cut into equal length 30 cm (300 mm) which constitute three node (i.e. 10 cm is the average length of a sugarcane node) [9]. The machine was then set into operation by the power source and known weights of sugarcane was fed into the sugarcane crushing unit. The sugarcane was inserted into the rollers where crushing, squeezing and pressing of the sugarcane occur as the sugarcane passes through subsequent rollers. The juice extracted from sugarcane is then collected in the collector from the discharge outlet. After the extraction, the mass of sugarcane fed into the machine was measured, the mass of juice extracted and mass of residual waste (bagasse) were also recorded. The mass of juice in bagasse was determined using the method provided in ASAE [10], which involved oven drying the bagasse at 130^oc until a constant weight was reached.

2.3 Performance evaluation indicators

The machine was evaluated based on the Output capacity, extraction efficiency and extraction losses using equation 1, 2 and 3 as described by Jenkins [11] and [12].

a) Output capacity C_o (kg/hr)

This is the rate of juice extraction in kg/h. This parameter was used to determine the juicing capacity of the developed sugarcane juice extractor.

$$C_o = \frac{W_e}{T} \quad (1)$$

C_o = Output capacity (kg/hr)
 W_e = Weight of juice extracted (kg)
 T = Total time taken for extraction (hr)

b) Extraction efficiency E_{ef} (%)

This is referred to as the juice extraction efficiency in percent. This parameter was used to determine the juicing ability of the developed sugarcane juice extractor.

$$E_{ef} = \frac{W_e}{W_p} \times 100\% \quad (2)$$

Where:

E_{ef} = Extraction Efficiency (%)
 W_e = weight of juice extracted (kg)
 W_p = juice present (kg)

c) The extraction losses are given by [13]

These are the losses due spillage, splashing and juice remaining in the bagasse.

$$E_L = \frac{100[(W_{fs}) - (W_e + W_{rw})]}{W_{fs}} \% \quad (3)$$

Where:

E_L = Extraction loss (%)
 W_e = Juice extracted (kg)
 W_{fs} = feed sample (kg)
 W_{rw} = Residual waste/ dry bagasse.

3. RESULTS AND DISCUSSION

3.1 Effect of Speed on Output Capacity

The results obtained from the measured samples for extraction capacity during the evaluation of the machine was plotted against speed of operation on a graph. From Fig. 3 it can be seen that the highest mean extraction capacity of 152.4kg/h was obtained using a crushing speed of 30 rpm for the first variety while the second variety recorded 154.2kg/h at the same speed. It can also be deduced from Fig. 3 that the mean extraction capacity increased from speed of 20 rpm to 30 rpm (i.e. 713 to 1069 rpm prime mover speed) where it attained the maximum output capacity and thereafter decreased with further increase in speed from 40 rpm to 60 rpm. This result corresponds with that of [14] whose output capacity increased from a grating speed of 602 to 1176 rpm. He got the maximum output capacity of 353.34kg/hr at a grating speed of 1176 rpm and then it starts to decrease from 1176 to 1520 rpm. According to their report, this increased in the means of extraction capacity with increased speed of operation may be as a result of proper crushing of cane stalks. But in the case of the decreased in mean value of extraction capacity noticed in the crushing speed of 40 rpm to 60 rpm may be due to diminishing return. Another reason could be that as the speed of operation increased, the torque required for crushing decreased and hence a decreased in output capacity. The slope is more steeper in the *koma* variety than in the *kantoma* variety and the reason may be due to the hard nature of the *koma* variety and it was suspected that at this high speed, the machine lacks the capacity to adequately crush the fibre to release the juice due to the hardness of the cane stalks.

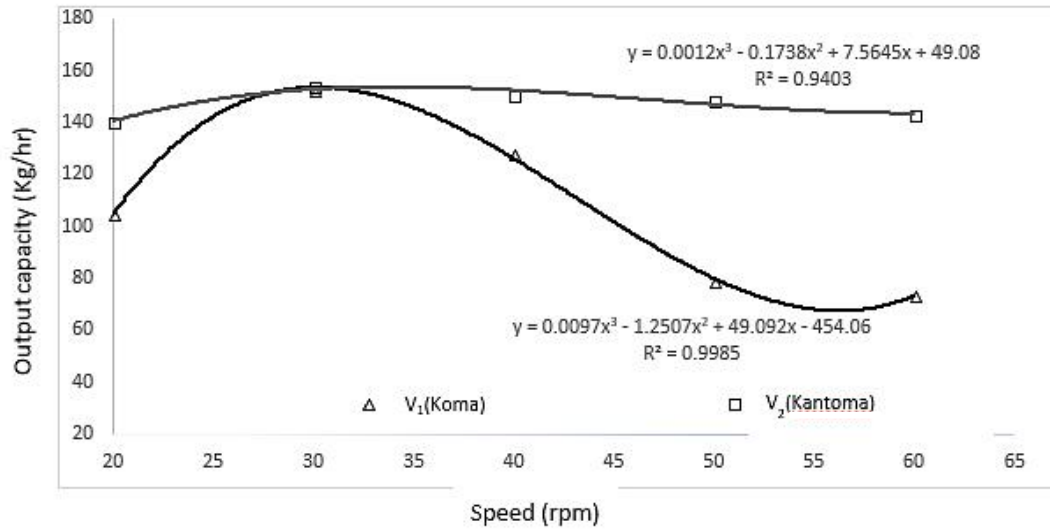


Fig. 3. Relation between speed and output capacity

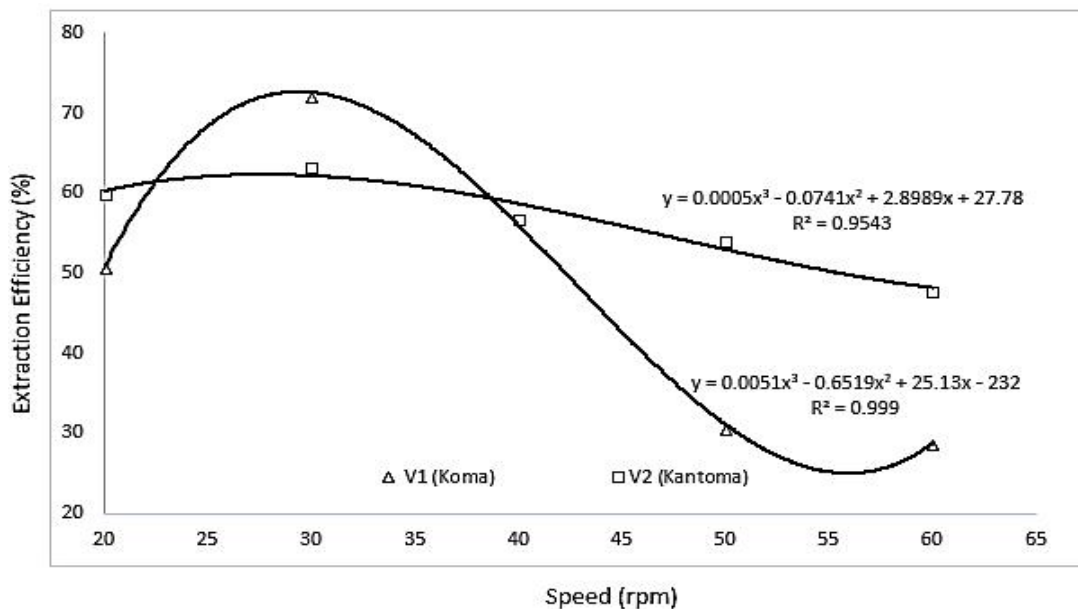


Fig. 4. Relation between speed and extraction

The graph was captured in a polynomial of order 3 with coefficient of determination (R^2) of 0.99 and 0.94 for *koma* and *kantoma* varieties respectively, which indicates that there exists a very strong relationship between speed and output capacity.

3.2 Effect of Speed on Extraction Efficiency

The results obtained from the measured samples for extraction efficiency during the evaluation of

the machine was plotted on a graph. Fig. 4 shows the relationship between mean extraction efficiency versus speed of operation.

It can be deduced from Fig. 4 that the mean extraction efficiency also followed the same trend with output capacity. The mean extraction efficiency increased from speed of 20 to 30 rpm (i.e 713 to 1069 rpm prime mover speed) where it attained a maximum extraction efficiency of 72.1 % and 63.4 % for *koma* and *kantoma* varieties respectively. This is in line with the

findings of [1] who recommended 30 rpm as the best crushing speed for sugarcane. This result is also similar to that of [14] in which they recorded the highest mean extraction efficiency of 46.84 % at grating speed of 1176 rpm. However, the machine behavior changes as soon as the recommended speed was exceeded. At the speed of 40 rpm, the extraction efficiency started to reduce steadily up to the speed of 60 rpm for *Kantoma*. However, *Koma* almost maintained a constant efficiency from the speed of 50 to 60 rpm. The efficiency of 72.1 and 63.4% obtained was higher than 46.84% obtained by [14].

The graph was captured in a polynomial of order of 3 having coefficient of determination “R²” of 0.99 and 0.95 for *Koma* and *Kantoma* varieties respectively, which indicates that there exists a very strong relationship between the speed and extraction efficiency. This R² values is higher than the one obtained by [14] which is 0.94.

3.3 Effect of Speed on Extraction losses

The results obtained from the measured samples for machine losses during the evaluation of the machine, the highest mean machine loss value of 17.8 % and 21.5% for *koma* and *kantoma* variety respectively was obtained using a crushing roller speed of 60 rpm. Fig. 5 shows the graph of mean machine losses versus speed of

operation. It can be deduced from Fig. 5 that mean extraction losses increased with increase in speed of operation. This may be due to the fact that at high speed, the machine is subjected to high vibration leading to splashing of juice around the body of the machine. Another reason could be that at high speed, the cane stalks just passed through the rolling press without adequate time for the juice to properly drain down. This is contrary to the findings of [14]. According to their report, at lower grating speed, the grating capacity is low which result in many ungrated cane stalks leading to high losses during grating. But at high grating speed, more cane stalks are grated hence reducing machine losses [15-17].

The coefficient of determination R² of 0.948 and 0.856 for *koma* and *kantoma* varieties respectively shows that there exists a very close relationship between the independent and the dependent variable.

3.4 Effect of Varieties on Output Capacity

When the means were subjected to Duncan multiple range test, the result revealed that *kantoma* variety have the highest mean output capacity while *koma* variety have the least and hence, *kantoma* is statistically significant with *koma*. Table 2 shows the result obtained.

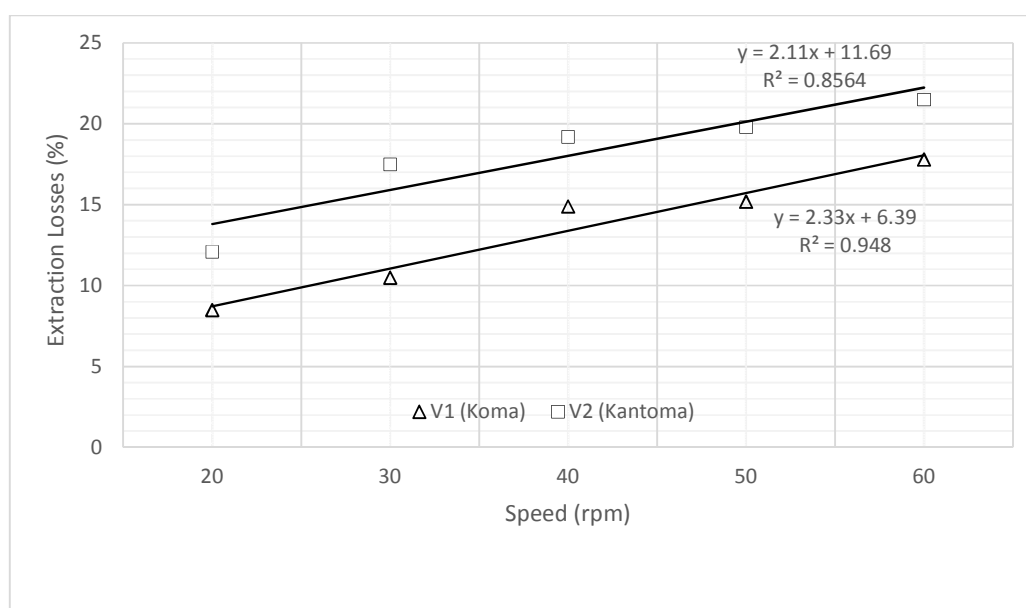


Fig. 5. Relation between speed and extraction losses

Table 2. Effect of varieties on output capacity

Varieties (V)	Mean output capacity (kg/hr)
2	145.68a
1	97.48b
SE+	2.835

3.5 Effect of Varieties on Extraction Efficiency

The results of the effect of varieties on extraction efficiency was assessed using Duncan multiple range test (DMRT) as presented in Table 3.

From the Table, *Kantoma* variety, recorded the highest mean hence the highest effect on extraction efficiency of 58.06% followed by *koma* 44.43%. Hence *Kantoma* variety was statistically different from *Koma* variety. Therefore, Duncan ranking showed that *Kantoma* has the highest effect on mean extraction efficiency.

Table 3. Effect of varieties on extraction efficiency

Varieties (V)	Extraction efficiency (%)
2	58.06a
1	44.43b
SE+	1.145

3.5.1 Effect of feed rate on extraction efficiency

The results of the effect of feed rate on extraction efficiency was assessed using Duncan multiple range test (DMRT) as presented in Table 3.

The results showed that the feed rate of one (1) cane stalk have the highest mean extraction efficiency while feed rate of three (3) cane stalks has the least. The mean extraction efficiency of feed rate of two (2) and three (3) cane stalks statistically the same, i.e. they have the same effect on extraction efficiency. The mean extraction efficiency of feed rate of one (1) cane stalk is statistically different from that of feed rate of two (2) and three (3) cane stalks. The Duncan ranking for feed rate shows that there exists an inverse relationship between feed rate and extraction efficiency. This implies that as the feed rate increased, the mean extraction efficiency decreased. Hence, it was suspected that feeding the machine excessively will eventually lead to reduced performance or the law of diminishing return.

Table 4. Effect of feed rate on extraction efficiency

Feed rates (stalk)	Mean extraction efficiency (%)
1	54.14a
2	50.01b
3	49.59b
SE+	1.402

4. CONCLUSION

The performance evaluation of the sugarcane juice extractor was carried out. The best output capacities of 152.4 and 154.2 kg/hr and the best extraction efficiencies of 72.1 and 63.4% for *koma* and *kantoma* varieties respectively at a speed of 30 rpm and at feed rate of one (1) cane stalk. The highest extraction losses of 17.8 and 21.5% was recorded at the speed of 60 rpm for *koma* and *kantoma* varieties respectively. It is therefore concluded that the best speed for operating the cane juice extractor is 25 to 30 rpm and the feed rate of one (1) cane stalk would yield the best efficiency.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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